Lead as a Stormwater Runoff Pollutant

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Lead is one of the constituents in urban area and highway stormwater runoff that is of potential concern to NPDES permitted stormwater runoff managers since its concentration in stormwater runoff can exceed US EPA water quality criteria and state standards based on these criteria. Lead is also of concern to stormwater managers because of its potential adverse impacts to human health as a hazardous constituent in soils and sediments. Pitt and Field (1990) reported that the US EPA National Urban Runoff Program (NURP) studies found that the median concentration of lead in US municipal stormwater outfalls was 150 µg/L. This concentration is well above the hardness adjusted allowable concentration in ambient waters that is considered to be adverse to aquatic life which for fresh water is about 1 to 7 µg/L and for salt water is about 5 µg/L.

The principal source of lead in highway and street stormwater runoff as well as soils in urban areas and near highways during the time of the NURP studies i.e., about 1980, was the use of lead as an additive in gasoline. Since that time, leaded gasoline is not generally used, and in some areas its use is prohibited in vehicles. However, the concentrations of lead in gasoline due to natural sources in the crude oil still often cause stormwater runoff from highways and streets to have excessive concentrations of lead compared to ambient water quality criteria/standards. While originally leaded gasoline contained about 250 mg/L lead, today unleaded gasoline can contain on the order of 15 mg/L lead. Further, many soils near highways and urban streets still contain high concentrations of lead from when it was used as a gasoline additive. These soils, coupled with the new lead added to them from vehicular traffic are sources of lead in stormwater runoff that represent potential public health and environmental threats.

This paper presents an overview review of the current understanding of the potential significance of lead in urban area and highway stormwater runoff as it may impact the beneficial uses of the receiving waters for this runoff. Further, information is provided on the current understanding of the potential public health significance of lead residues in soils and sediments as they may impact children's health.

Contaminated Soils

One of the areas of particular concern to stormwater dischargers in California is the Department of Toxic Substances Control's (DTSC) definition of "hazardous waste" which includes a total lead content of the wastes. Any soil or sediment that is a waste that has over 1,000 mg/kg dry weight total lead is, according to current California policy, a hazardous waste. This regulatory total threshold limit concentration (TTLC) is causing Caltrans District 7 (Los Angeles District) to spend many millions of dollars per year cleaning out Caltrans highway stormwater runoff catch basins where the removed material is handled as a hazardous waste since the concentration of lead in the material exceeds the DTSC limit for total lead in a waste. This situation arose out of a court order where the NRDC filed suit against Caltrans for failing to properly implement its stormwater runoff water quality management programs required under its NPDES permit. The judge concluded without adequate review in issuing his ruling on the lawsuit, that any material that is classified as a hazardous waste must be adverse to the environment. However, as discussed below, a critical review of this situation shows that the lead in stormwater runoff from urban areas and highways is in a non-toxic, non-available form and is not adverse to aquatic life in an aquatic environment. The DTSC hazardous waste classification was not based on aquatic environment considerations, but based on human health which can include ingestion of the wastes and the solubilization of the lead in the wastes at the low pH that occurs in a child's stomach.

Lead Containing Soils as a Hazardous Waste

Mahmood (1996) developed a review of lead contamination in soils near highways. His review shows that while many soils near highways and in storm drainage ponds contain lead at less than 500 mg/kg, some soils near highways have lead concentrations above 500 mg/kg and few above 1,000 mg/kg. Lee and Jones-Lee (1992) have reported that urban area soils and sediments near highways and streets frequently contain lead at concentrations above 500 mg/kg. There are some soils and sediments near major highways and in urban area centers that have lead in excess of 1,000 mg/kg. This lead is in a particulate form and tends to accumulate in stormwater conveyance structures and is removed in detention basins and filters. There is a potential for concentrations of lead in the sediments and soils associated with urban streets and highways to exceed the DTSC 1,000 mg/kg TTLC value.

The California DTSC is in the process of re-examining its hazardous waste classification system which causes some wastes in California to be classified as hazardous wastes but are not classified as hazardous wastes by the US EPA and other states. This California-only hazardous waste is, through increased cost of waste management, placing an economic burden on the California public. As discussed herein, the public health hazards associated with lead in soils have been investigated in detail since the state of California adopted the TTLC value for lead of 1,000 mg/kg in the early 1980s. The current DTSC hazardous waste classification review could lead to a more appropriate assessment of whether highway and urban area street stormwater runoff-associated lead that accumulates in stormwater conveyance and treatment structures, such as detention basins, requires management as a hazardous waste. This management greatly increases the costs of disposal of lead contaminated soils and sediments compared to their disposal in a municipal sanitary landfill. The nature of the municipal solid waste stream is such that it routinely contains soils and other materials with concentrations of lead above 1,000 mg/kg which are deposited in municipal landfills.

However, since these are derived from domestic sources they are exempt from being classified as being a hazardous waste.

Recently DTSC has proposed to raise the TTLC value for lead from 1,000 to 8,500 mg/kg. Since urban soils typically contain total lead concentrations from 500 to 1,500 mg/kg, the proposed revised TTLC value for lead could eliminate the classification of soils/sediments associated with highway and urban streets stormwater runoff that accumulates in highway and urban street stormwater conveyance and treatment structures as being classified as a hazardous waste. Adoption of this approach would more appropriately regulate the lead in soils and sediments associated with stormwater runoff from highways and urban streets than is being done today.

Lead as a Threat to Children's Health

Lead is recognized as one of the most significant environmental causes of adverse impacts to the health of children. Young children tend to be impacted by lead through neurological damage at much lower concentrations than have been found to impact adults (ATSDR, 1993). Chronic exposure of children to lead is also adverse to children's growth (Kim *et al.*, 1995). Of particular concern is children's ingestion of lead-based paints. Also of concern is the ingestion of lead containing soils. While there are well established links between children being exposed to lead-based paint and blood lead levels that are considered adverse to a child's health, the linkage between lead in soils in which children play and blood lead levels is tenuous. Tsuji and Serl (1996) found that there was a poor correlation between children's blood lead levels and soil lead concentrations below 1,000 mg/kg.

Lee and Jones-Lee (1992) reviewed the various regulatory approaches that have been adopted in the US and other countries to protect children from adverse impacts from soil lead. In the early 1990s there were a number of regulatory agencies that established critical soil lead levels of 50 to 100 mg/kg. The Society for Geochemistry and Health (Wixson and Davies, 1993) developed recommended guidelines for lead in soils which involved a complex relationship between soil lead concentrations and blood lead levels. Additional information on the significance and control of soil lead and lead based paint children's health issues is available in the conference proceedings edited by Beard and Iske (1995).

The US EPA (1994) developed an integrated exposure uptake kinetic model for lead in children's environment and blood lead levels. Based on this modeling approach, it is recommended (Alliance, 1994) that soil lead concentrations below 400 mg/kg is not of concern. In the concentration range of 400 to 2,000 mg/kg, restrictions should be implemented to reduce childrens exposure to the bare soil. No further investigation is generally considered necessary in this concentration range. Above 2,000 mg/kg soil lead, a public notice of the lead contaminated soils should be issued and the conditions should be monitored. Interim controls to establish barriers to reduce the access of children to the lead contaminated soils should be implemented. Above 5,000 mg/kg, the US EPA recommended approach requires removal and replacement of soils or establishment of permanent barriers.

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From the information available today, the DTSC waste lead classification, which classifies any soil that is a waste with a lead concentration above 1,000 mg/kg as a hazardous waste, is significantly out of date and highly overprotective. This is the impetus behind DTSC's current proposal to raise the lead hazardous waste classification limit to 8,500 mg/kg. Even the 1,000 mg/kg value appears to be overprotective for children's occasional contact with soils containing lead at this value. The current Caltrans situation of court ordered spending of large amounts of public funds for control of soils and sediments associated with highway stormwater runoff because some of the particulates in this runoff that accumulate in conveyance structures and treatment works contain concentrations of lead above 1,000 mg/kg, is technically invalid.

While the US EPA does not, at this time, include total lead or other constituent concentrations as a basis for classifying hazardous wastes, there have been some discussions about the possibility of adopting that approach. It is doubtful, however, that if the Agency did adopt a total lead concentration for classification of hazardous wastes that it would cause soils and sediments associated with highway stormwater runoff to be classified as a hazardous waste since such classification would cause many soils in urban centers to also be classified as a hazardous waste. Such a classification would be counter to the normal approaches being used today in hazardous waste management.

US EPA Hazardous Waste Classification

The US EPA's approach for classification of waste materials as hazardous waste primarily relies on examining whether the regulated constituent is leached from the waste material under conditions that are said to simulate, to some extent, the conditions that would exist in a municipal sanitary landfill. Originally, the Agency used an acetic acid leaching solution to leach the waste materials in the Extraction Procedure Toxicity Test. This was replaced by the Toxicity Characteristic Leaching Procedure (TCLP). The waste material is still leached under standardized conditions with acetic acid, and the amount of leachable constituents, such as lead, is compared to the US EPA drinking water standard (maximum contaminant level - MCL). A factor of 100 times the drinking water standard is used to determine whether a waste material leaches excessive lead or the constituents regulated by this approach. This factor of 100 is a so-called attenuation factor that is said to be based on the average attenuation that would occur in transport of leachate polluted groundwaters between the base of the landfill and a drinking water well. In fact, the attenuation factor of 100 was arbitrarily developed and is overly protective in some cases and underprotective in others depending on aquifer characteristics and the proximity of the well to the landfill. Lee and Jones (1981) have reviewed the problems with the US EPA's hazardous waste classification procedures and discuss the development of a site specific evaluation that would more appropriately classify materials as a hazardous waste than is being followed today.

At the time the TCLP test was first developed, the drinking water MCL for lead was 50 µg/L. This allowed a 5 mg/L leachable lead as the break point between nonhazardous and hazardous wastes. Subsequently, the Agency decreased the drinking water standard (action level) to 15 µg/L. The Agency, however, did not continue with its factor of 100 times the MCL to establish the leachable lead but allowed it to remain at 5 mg/L rather than the value of 1.5 mg/L which should have been adopted if the factor of 100 was used consistently. This situation is of some importance to highway and urban area stormwater runoff management because DTSC, as part of its revisions of the hazardous waste classification approach, has proposed to eliminate the use of the citric acid leaching procedure (Waste Extraction Procedure) that California adopted some years ago, which leads to a California only hazardous waste based on the difference between the US EPA TCLP results and those of the California Waste Extraction Procedure. Citric acid tends to extract more metals from waste materials than acetic acid. DTSC, however, has proposed to set the leachable lead in the TCLP to the 1.5 mg/L level, i.e. 100 times the current drinking water action level.

If DTSC follows through with this approach, soils near highways and urban streets, which are not now classified as hazardous waste based on US EPA TCLP based procedures which allow up to 5 mg/L of extractable lead, could become hazardous waste under the California TCLP procedure which would allow 1.5 mg/L extractable lead. It is the authors' experience that while few soils with gasoline-derived lead show TCLP extractable lead at 5 mg/L, there are soils that have extractable lead above 1.5 mg/L. There is need to examine TCLP results for soils from highway and urban area vehicular-derived extractable lead to see if they exceed the 1.5 mg/L level proposed by DTSC.

One of the most significant misuses of the US EPA TCLP procedure results is to determine whether soils containing a constituent regulated by the US EPA through TCLP is a hazardous waste and therefore must be removed from its current location. While the EP Tox test and TCLP test were never intended to classify soils and sediments as a hazardous waste and therefore require management in which concentrations below the hazardous waste classification level are considered "safe" and those above this level are considered hazardous, often, federal, state and local regulatory agencies inappropriately use the TCLP test results for this purpose. As discussed herein, TCLP was only meant to simulate conditions similar to those in a municipal solid waste landfill in which there is a pH of about 5 and a high organic content. It does not simulate the conditions that occur in typical urban or rural soils that would influence the leaching of lead and other constituents from the soil. The TCLP test would tend to leach far greater amounts of lead than typically occurs in rain water or surface water leaching. Lee and Jones (1981) discussed the development of site-specific leaching tests to more properly evaluate whether a constituent in a soil/sediment is a potential threat to aquatic life because of potential leaching of hazardous substances. The US EPA has proposed modifications of the TCLP test to more appropriately simulate environmental leaching conditions than those that are present in the TCLP test.

In summary, the hazardous waste classification situation, with respect to soils with vehicular traffic-derived lead such as occurring near urban area streets and highways, is in a state of transition in California. Over the next few years there will likely be significant changes from those that exist now in the classification of soils and sediments that become wastes with respect to whether these wastes must be disposed of in a hazardous waste landfill or can be disposed of, usually at much less cost, in a municipal solid waste landfill. Further, while it is inappropriate to do so, the current and future classification procedures will be used to determine whether a lead contaminated soil can be

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left in place or should be removed and taken to a hazardous waste landfill for management because it is classified as a hazardous waste.

Stormwater Runoff Lead Impacts on Water Quality

Since today's highway and urban street stormwater runoff frequently contains total lead at concentrations above the US EPA water quality criterion and state standards based on this criterion value, there is concern that the stormwater runoff from urban areas and streets will cause an exceedance of the lead standard in the receiving waters for the runoff. This is especially true for those states that are using total heavy metal concentrations rather than soluble heavy metal concentrations as the regulatory basis for regulating lead and several other heavy metals. As of May 1995, the US EPA (1995) has adopted soluble lead as the regulatory basis for regulating lead in ambient waters where the issue of concern is impact on aquatic life.

Peterson (1973) working under the supervision of the senior author, Dr. G. Fred Lee, conducted a PhD dissertation devoted to the aqueous environmental chemistry of lead in Wisconsin lakes. Of particular concern were the high concentrations of lead found in highway and urban area street runoff. At that time, late 1960s-early 1970s, extensive use of leaded gasoline was practiced. This caused stormwater runoff from streets and highways to contain high concentrations of particulate lead. The Peterson studies showed that this lead remained in a particulate, non-toxic, non-available form in the receiving waters water column and sediments for the highway and street stormwater runoff.

Water Column Impacts

Regulating lead as soluble lead rather than total lead has been recognized as the appropriate approach since the early to mid-1970s. The NAS/NAE (1973)Blue Book of Water Quality Criteria of 1972 recommended that lead be regulated on toxicity testing since it was not possible, through chemical measurements, to predict toxic forms. The US EPA (1976) in its Red Book of Water Quality Criteria recommended that lead be regulated based on soluble lead rather than total lead.

While some stormwater managers are devoting efforts to develop lead control programs in stormwater runoff from city streets because of the exceedance of water quality standards for total lead in the runoff waters, such an approach can result in large expenditures of public funds with no impact on the beneficial uses of the receiving waters for the stormwater runoff. Because of the extensive work that has been done on the potential environmental impacts of highway and street stormwater runoff associated lead on receiving water aquatic life and other beneficial uses, it will be indeed rare that real water quality problems occur in the receiving waters for the stormwater runoff due to an exceedance of the water quality standard for total and soluble lead.

Stormwater quality managers should determine total and soluble lead in the runoff waters. If the concentrations are less than the US EPA criterion value, then it can be appropriately assumed that the lead in these waters does not likely represent a significant water quality problem in the

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receiving water water column. As discussed by Lee and Jones-Lee (1995, 1997a), if the concentrations are above the ambient water standard then the first step that should be followed before any lead runoff control program is formulated, is to investigate whether the "excessive" lead in the stormwater runoff is causing a real water quality use impairment in the receiving waters for the runoff. This will typically require a site-specific investigation of the water quality impacts of the elevated lead in the stormwater runoff. By following the Evaluation Monitoring procedures developed by Lee and Jones-Lee (1996a,1997b), which focus on aquatic life toxicity assessment and appropriate use of TIEs, it is possible to determine whether the lead in the stormwater runoff that exceeds water quality standards is causing a real water quality problem-use impairment in the receiving waters for the runoff. This is a far more technically valid, cost effective approach that the approach being used by some stormwater managers to address the exceedance of the lead water quality standard in stormwater runoff waters.

Sediment Quality Impacts

Since the lead in urban area highway and street stormwater runoff is typically in a particulate form, it will accumulate in the receiving water sediments. It should not be assumed, as has been done in the Santa Monica Bay, California Restoration Project (see Lee, 1995), that the presence of lead in stormwater runoff receiving water sediments represents a significant sediment quality/water quality use impairment that requires the construction of structural BMPs to control the lead input to the waterbody from urban area streets and highways. Also, it should not be assumed that chemically based sediment quality criteria or co-occurrence based values for sediment quality guidelines are reliable for estimating the potential water quality significance of lead, or for that matter any other constituent, in sediments. As discussed by Lee and Jones-Lee (1993,1996b), site-specific investigations using appropriately conducted sediment toxicity tests and TIEs should be used to determine whether lead in sediments is in a form that is adverse to aquatic life within the sediments and within the waterbody in which the sediments are located. It is the authors' experience that it will be, indeed, rare, if ever, that urban area street and highway stormwater runoff-derived lead will be in a toxic, available form in receiving water sediments in sufficient concentrations to be significantly adverse to the beneficial uses of the waterbody.

Bioaccumulation of Lead

Lead is one of the chemicals of concern in urban area and highway stormwater runoff for which neither the FDA nor the US EPA (SFRWQCB, 1995) has developed critical tissue concentration values. Recently, Cox (1997) determined that lead concentrations in fish tissue above 0.3 mg/kg would represent hazardous levels to children who consume an average of 54 g/day of fish. This fish consumption amount is slightly higher than the US EPA value of 30 g/day, but is on the order of one meal per week. Consuming fish with concentrations of lead above this value would represent a threat to a child's health similar to the threat associated with drinking two liters of water per day with concentrations of lead above the US EPA action level of 15 μg/L.

Overall Assessment

Based on current public health and aquatic life impact knowledge, it will be rare that lead in urban area and highway stormwater runoff will be significantly adverse to aquatic life that are in the receiving water water column or sediments for the runoff. Also, it will be rare that lead that accumulates in soils near highways and in stormwater runoff conveyance structures will be adverse to public health, aquatic life and the environment. Those stormwater managers who face an excessive lead situation should first evaluate whether the basis for judging "excessive" is technically valid where water quality or public health impacts would be expected, or represents inappropriate standards by which "excessive" is being evaluated. There is need to help DTSC revise its current approach for regulating lead as a hazardous waste to incorporate more appropriate assessments of the public health significance of lead in soils. There is also need to assist the US EPA and the state of California to develop more appropriate criteria/standards than exist today for urban area and highway stormwater runoff-associated lead.

Further Information

For further information on this topic area, consult the authors' web site: http://members.aol. com/gfredlee/gfl.htm, where they make available as downloadable files their papers cited herein.

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